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revolutionize artesian well boring. The practical results of all experiments have been perfectly satisfactory. The water does not injure either soil or vegetation. It is used constantly on the lawns about scores of residences, in Huron, Aberdeen, Redfield and Mitchell. It can be applied directly to the crops whenever needed. But ordinary agriculture in Dakota requires simply an overflow of the land in the spring or fall, and with a saturated sub-soil, and the air moistened by a multitude of artificial lakes, the wide fields of South Dakota will wave with wonderful harvests year after year.

The Melville law just in force authorizing the bonding of townships for the purpose of putting down artesian wells is being received with great favor, and will furnish the funds to start the streams of a lasting prosperity in this vigorous young commonwealth

April 7, 1891.

SOURCES OF THE CONSTITUENTS OF MINNESOTA SOILS.

By C. W. Hall.

CONTENTS.

The soil is the superficial portion of the unconsolidated surface material of the globe; it is the line of contact between the solid portion—the rocks—of the earth's crust and the liquid or gaseous portion—the air and the water. It is, therefore, the zone of chemical activity and represents that era of profound change, under which rocks break in pieces and re-form under new physical conditions and chemical composition; under which water is absorbed by the rocks or, unabsorbed, becomes loaded with every conceivable chemical element and compound as it passes on in its devious wanderings.

The Formation of Soils. Touching the formation of soils two things may be noted: (1) The soil is made of debris of weathered and comminuted rocks mingled with the remains of plants; (2) Since the composition of vegetation is always nearly the same, the varying conditions of soils must depend upon two things, the proportion of vegetable remains in the vegeto-mineral mixture and the variation of the rock constituents out of whose decomposition the mineral portion is obtained. Vegetation in its decomposition plays rather a chemical than a geological part. In the course of years, large quantities of vegetable matter are broken down and are subjected to the various processes of decay. In some instances peat is formed; in others, the vegetable matter is mingled with mineral to such an extent that it becomes a carbonaceous rock.

Mineral matters in the mixture usually take the leading place and are of prime importance in considering the character of soil. The two extremes of infertility in soils are clear, comminuted quartz, kaolin and calcite,—that is, sandstone, clay and limestone,—on the one hand, and clean vegetable mold on the other; and all the stages of fertility lie between these extremes, where the sandstone, shale or the limestone, and mold are judiciously mingled and associated with proper proportions of alumina and the alkalies.

The process of rock alteration.—The process by which the chemical condition of rocks is changed so that they may become constituents of soils is rock alteration, and this is one of the most constant processes in nature. It is going on wherever water and air can come in contact with the rocks; so it is not only along the comminuted surface that is exposed to the sunshine, where we call it weathering, but along the deep fissures which extend for many feet—even miles—through the rocks in vertical and horizontal directions. The processes by which alteration is effected vary under different conditions. This change is effected in warm and humid climates chiefly by waters of a comparatively high temperature, in climates that are warm and dry, by sunshine and sudden changes of temperature; in cold climates, by moisture and freezing. But with these forces, others naturally come into play; for instance, the erosion of rain water is necessary to remove the loosened material, so that which lies below and still fresh, may come within the influence of weathering agencies; or the wind, blowing through high arid regions with great violence, carrying clouds of dust, constantly lays bare the surface of underlying rocks and burrowing animals of many types constantly bring to the surface quantities of fresh earth.

The layers of soil sections.—In any normal soil section there are three layers, (1) the soil; (2) the sub-soil; (3) the underlying rock. The soil is filled with the roots and rootlets of plants, and the burrows of insects and worms. Plants are constant constituents of soils. Numerous fungi and plants of many a low type abound.

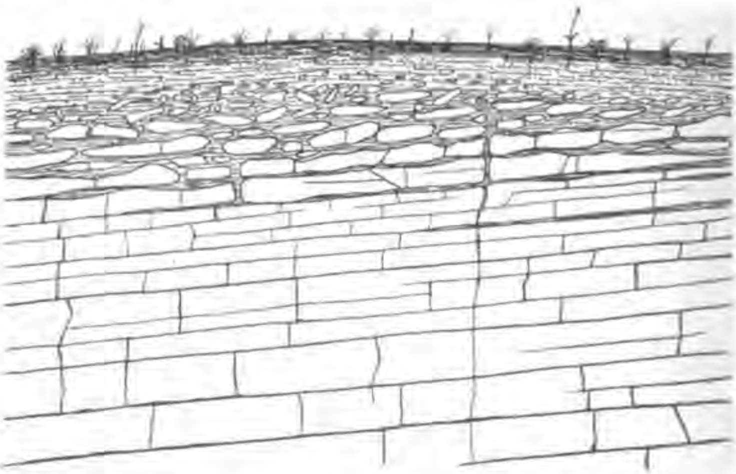

Figure 1. The decomposition of limestone and the foundation and accumulation of soil. This is representative of areas in Southeastern Minnesota. Drawn by F. W. Sardeson.

The sub-soil is a broken-up layer consisting of pebbles large and small, some crumbling and others fresh, around which are pushing their crooked ways the roots of trees and strong herbs. In color this layer is like the rock beneath; and while in general characters it touches on the rock below, in other characters it is closely related to the soil above. A loam, a clay, a sand, or a gravel bed beneath a cultivated field is sure to make its imprint upon the crop raised. The reason for this is not far to seek: it lies within the observation and every-day experience of every one. Water will disappear by the barrel in sand and gravel; while it will lie until it dries up when the bottom of the pool is clay or mud.

The underlying rock is compact and firm, never fresh and unshattered, and never yielding to the urgent demands of the growing trees for root space or support, unless it has first yielded to the action of water and the crustal movements of a changing globe. The varying proportions of the soil to the sub-soil, and the sub-soil to the underlying rock are often noted. They lie in the varying conditions under which soils are formed and retained

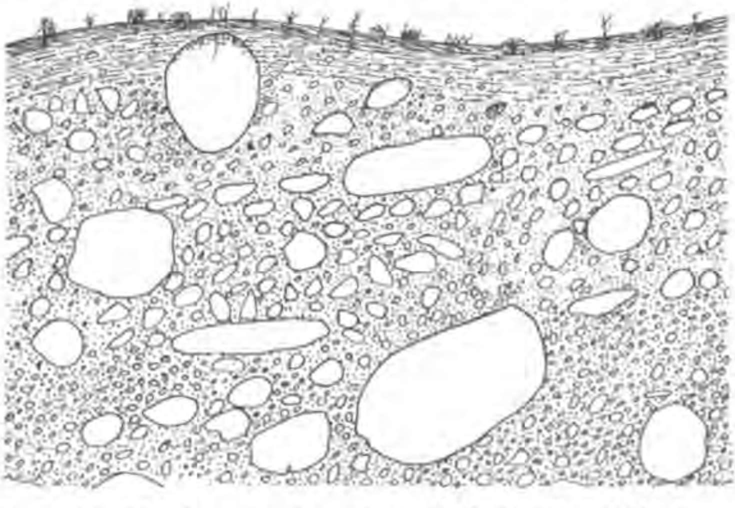

Figure 2. The decomposition of glacial drift, till, and the formation of soil. This is the type of rock alteration and soil building most extensive in Minnesota. Drawn by F. W. Sardeson.

in place. Upon hillsides there is a constant transport of material towards the bottom. If the slope be gentle, this transport is slow. and in any case it is the finest particles that are carried farthest. This movement while slow and insignificant in itself, is of moment since it forms the record of a slow and almost imperceptible geological change affecting a whole region. This change suggests another fact within observation: a given type of plant growth will continue to live generation after generation upon the same place. This is the case because the peculiar food constituents which are favorable to the growth and maturity of this particular species are continually loosened and separated from the rocks in which they lie, and in the course of time they are comminuted by temperature changes and rain water at so slow a rate as to furnish plants food at about the same rate as they exhaust it by assimilating it. The great diversity of composition and physical characters which soils present are really primary traits and they depend to a great degree on the nature of the rocks beneath the surface and the topographical features of the country in which they are found. Other traits are secondary; briefly enumerated, they are due:—to depositions of vegetable and animal matter; to the action of moles, worms, insects; to the growth of roots of trees; the wind which, in leveling countries, moves great masses of the finer soil, and to those slow but unceasing chemical activities which transform entire rock formations and extend over the continental areas of the globe.

Darwin fifty years ago noted the peculiar creeping of soils by which lower layers would seem to change places with upper ones, and this apparently without the aid of worms or moles. This phenomenon is probably explained by the capillary action possible through the pressure of water. Underground waters also equalize the temperature of soils to a most remarkable degree, a fact of great moment in the steady growth of crops in a changing climate like ours.

The work of the sea in the forming of soils.—While it is not necessary to call attention to those soils formed directly by the sea, still we note that indirectly the work of the sea in the building of all soils is an imposing one. The beginning of this work lies in those silent and ceaseless ages in which the contents of the vast oceanic basins were brought into one compound after another, and at the close of many transformations—some of which transformations are made in the tissues of plants and animals and others in the vast abysmal precipitations by which alumina, iron, silica, and the alkalies,—are packed down on the bed of the sea. Thus the waters of the sea play no insignificant part in soil building, although it is a very indirect one.

The part of plants in soil formation. Plants are builders of soils; such is not always their office. They are also destructive in their action, disintegrating rocks by keeping the surface moist, —water being a medium of chemical action, and in itself a universal solvent. Plant decay furnishes an important source of organic acids. These acids in their action upon minerals and rocks are as vigorous as sulphuric or nitric acid of soils. Roots of plants—especially of trees and shrubs—pry off blocks of rock, separating them from the ledge and thus extend the rock surface over which corroding influences can work.

Effect of moisture in soils.—A practical note may be added touching the presence of moisture in soils: Cultivation varies that ingredient in all soils; experiment has shown this. The Michigan Agricultural College during the past few years, has been conducting a series of experiments upon different kinds of soils, and the following result is reached: The steady loam soil that is cultivated has three per cent. more moisture than that which is merely raked; and that which is raked, has one per cent. more moisture than unworked soil. This is a strong argument put in a strong way in favor of industry and care on the part of the farmer who has planted his crop.

The chemical elements in soils.—Dr. T. Sterry Hunt calls attention to the providential fact that those substances which the waters percolating through the superficial rocks take out and carry away are the substances which plants do not want, and the very substances which the waters leave are those which plants want and must have in their growth. "Drainage waters of soils, " he says, "like that of most mineral springs contain only carbonates, chlorides and sulphates of lime and magnesia and soda, the ammonia, potash, phosphoric and silicic acids being retained by the soils."* Briefly stated, those elements out of which are made the salts so essential to growing plants is in part the air, but in larger part the porous rocks of the earth's superficial crust through which the waters percolate, and from which they dissolve some essential ingredients. The number of these elements is not large. They are all grouped together under the general name *foods.* Some are used directly, others indirectly; some perform one office in the plant economy, others another and widely different one; some can be used immediately by the plant protoplasm

* Chemical and geological essays, The Chemistry of Metamorphic rocks, 2nd ed., 1878, p. 22.

and others must be worked over in divers ways. All these changes direct and indirect, immediate and remote are necessary to convert chemical elements and compounds into protoplasmic food, that is, to assimilate them.

The essential food elements of plants.—There are twelve chemical elements which may be considered the essential foods of plants: Of these six occur in large amounts, viz: Carbon, oxygen, hydrogen, sulphur, phosphorus and nitrogen; and six others in small amounts, viz: Calcium, magnesium, iron, silicon, potassium and sodium. Let us now see what extent these food elements exist in Minnesota rocks and, proportionately, in the soils derived from them.

Quite as essential as the mineral matters or the average moisture in the soil are occasional showers of rain. Dry weather causes the soil and sub-soil to hold these constituents as solids, and in this condition plants cannot take them up; but let a shower fall and dissolve them and they are rapidly carried into the plant tissues and there assimilated. A hint at this condition is seen upon prairies in the almost white coating of magnesic and calcic salts that cover the dark loam in the dried out sloughs and swamps of nearly every portion of Minnesota. A shower of rain will cause this white coating to disappear, again to appear as soon as the rain has been absorbed by the earth or evaporated once more into the air.

Here is the reason for the phenomena often seen in dry weather of the lower and mature leaves of a plant shriveling and disappearing; the salts so essential to the growth of the new shoots and leaves of the plant are taken from the mature parts of the plant itself instead of from the soil, where they lie in the condition of salts on which it is impossible for the plant to feed.

The chemical composition of soils.—When soils are spoken of in their chemical relations to plants and plant food the chemical composition of soils should be understood that the capacity of soils to feed plants may be seen. When the sources of the constituents of soils are discussed the amount and character of these constituents should be known. So little work has thus far been done on the chemistry of Minnesota soils that the following table is made up of analyses drawn from the geological survey reports of Wisconsin. They are taken from Salisbury's table, vol. 1, p. 307, as fairly representative of similar soils of Minnesota.

I. Peaty Soil—characteristic of the bottom lands of eastern Wisconsin.

II. Prairie Loam—south central Wisconsin.

III. Siliceous red clay, Ashland. This is fairly representative of an extensive stretch of country in eastern Minnesota.

IV. Loamy soil, Douglas county, Wisconsin, characteristic of the higher ridges and rolling areas of eastern Minnesota.

V. Sandy soil from the barrens of Douglas county, identical in general characters with the sandy tracts of eastern central Minnesota.

	I	II	III	IV	V
Silica SiO_2	64.49	79.59	57.60	80.36	94.08
Alumina AlO_3	4.80	4.17	25.85	2.90	0.74
Ferric oxide F_2O_3	5.74	8.16	4.11	0.90	1.00
Manganic oxide Mn_2O_3	0.13	0.18	......	......	......
Lime CaO	1.60	1.30	3.58	0.68	0.64
Magnesia MgO	0.79	1.04	1.70	0.40	0.12
Soda Na_2O	0.51	0.40	......	......	......
Potash K_2O	0.14	0.10	......	......	......
Phosphoric acid P_2O_5	0.12	0.06	......	......	......
Carbonic acid CO_2	0.25	0.52	4.65	0.70	0.65
Sulphuric SO_3	0.08	0.03	......	......	......
Water H_2O	......	......	2.57	3.15	0.37
Organic matter	21.40	4.24	......	9.60	0.80
Totals	100.00	100.00	100.00	98.78	98.40

Soils classified.—Powell classifies soils in the following manner:

I. Endogenous,—those derived from the common rocks, and remaining in place. These vary greatly according to the rocks from which they are derived; but broadly stated we have three classes:

1. Sandstone soils;
2. Limestone soils;
3. Granitic soils.

II. Exogenous soils,—those derived from other surfaces than that of the common rock peculiar to the district in which they occur. Of these soils there are many sub-divisions, but so far as represented in Minnesota, they are,—

1. Alluvial soils, formed from depositions on flat plains by running waters;
2. Lacustrine soils, formed from depositions in lakes;
3. Drift soils, formed from depositions by glacial agencies.

This classification can be considered only in a general way since the entire state, save a small area in the southeastern corner has been overwhelmed by glacial ice and its soil and subsoil conditions completely altered. The material torn up and comminuted has been transported and redeposited in other localities, some near and some far. Thus the rocks have been brought into even closer relations to the processes of soil-making than could exist were the surface of the state that of a non-glaciated region. The intermingling of material affords soil material of remarkable versatility and strength; versatility because of the intermingling incident to glacial transportation, and strength because of the mixture of partially decomposed and fresh materials, insuring a slow and continuous decomposition of mineral matters and a facility for the extended growth of roots and underground stems and thereby the ceaseless forming of soil to an unusual depth. That there are many rock species in the constitution of the glacial drift the following tables will show.

The rocks that form Minnesota soils.—The underlying rocks of the state are:—

1. The acid crystalline rocks,—largely granitic and rich in silica.

2. The basic crystalline rocks,—diorites, diabases, gabbros, etc., or those usually poor in silica.

3. Sandstones and quartzites, consisting mostly of silica.

4. Calcareous shales, partly carbonates of lime and magnesia, partly silica and partly alumina, as leading constituents.

5. Carbonates,—rocks chiefly of organic origin and chiefly carbonates of lime, magnesia and iron.

The first group of rocks includes granites, gneisses and the so-called crystalline schists. All are very hard to break down into the condition of soil. It takes time and chemical action. The chemical substances in these rocks are silica, alumina, potash, soda, lime, magnesia, and the compounds of iron. Quartz and the feldspars are their chief constituents, followed by hornblende, biotite, etc.

They are the chief storehouses of the elements furnished to the soil by these rocks, and in their degradation, the chief resultant products are quartz, sand and kaolin, with chloritic minerals in proportion to the biotite present. The granitic rocks, when broken down on level tracts, make a very sterile and barren soil; where erosion can collect them into valleys, the soil becomes rich —when not too heavy. But then, the cost! Hundreds of acres are washed to build a single meadow; and these washed hillsides are pre-eminently the barren pastures of grazing districts.

The granitic rocks.—Granitic rocks are distributed very largely over the northern part of the state. Probably one-half of the area north of the line from Taylor's Falls to Anoka and thence directly westward to the state of South Dakota through New Ulm and Tracy is underlain, beneath the glacial drift, by these rocks. At many places when the granites come to the surface samples have been taken for study. Below are a few analyses made of granites and gneisses from representative localities:

I. Red hornblende biotite granite, St. Cloud, analysis by F. H. Crowell.

II. Gray hornblende biotite granite, St. Cloud, analysis by W. H. Willard.

III. Gray augite granitoid gneiss, La Framboises farm below old Fort Ridgely; analysis by A. O. Dinsmore.

IV. Medium colored hornblende biotite granite, St. Cloud; analysis by G. H. Hammond.

V. Red hornblende biotite granitoid gneiss, Ortonville; analysis by A. D. Meeds.

(This is the stone of which the City Hall and Court House in Minneapolis is built.)

VI. Augite gneiss, La Framboise's landing below Ft. Ridgely, Otto H. Folin.

	I	II	III	IV	V	VI	**Average**
Silica SiO_2	73.30	71.64	72.30	69.47	74.70	69.07	71.71
Alumina Al_2O_3	14.20	11.82	15.40	14.94	14.06	13.73	14.02½
Ferric oxide Fe_2O_3	5.40	3.94	3.10	4.07	*5.07	*2.87	4.07½
Lime CaO	3.00	1.41	3.75	1.60	1.73	3.70	2.53
Magnesia MgO	0.50	0.32	0.65	0.29	0.29	7.08	.52
Potash K_2O	1.40	2.49	......	4.56	1.83	2.33	2.10
Soda Na_2O	2.00	5.22	3.40	3.37	2.17	4.30	3.39
Water H_2O	0.30	0.88	2.00	.....	0.26	0.13	.59½
Totals	100.10	97.72	100.50	98.30	100.11	97.05	98.98

*Fe_2O_3 and FeO computed together.

The foregoing analyses were made from fresh material, in some instances broken from the lowest layers in the quarry. They thus represent not partially decomposed rock formations, but the actual condition of the freshest and least changed beds within the granitic group of Minnesota rocks. The soils originating directly from them are as varied in composition as are the rocks themselves; so they vary from a sandy soil on the one hand when the rock is mostly silica, to a clayey soil on the other, when alumina occupies the largest place in the chemical composition of the rocks.

Basic eruptive rocks.—The second group, or the basic eruptive rocks are important, first, because of their extent, for probably ten thousand square miles of the commonwealth is underlain by these; and secondly, because of their chemical qualities. They possess the same chemical constituents as the first class considered, but in quite different and more varying proportions. They contain less silica and more of the alkalies and alkaline earths, the real plant food than do those. For instance, the lime in a cubic mile of these rocks, if none of it were wasted or used in other ways, is sufficient to grow a crop of grass yielding two tons per acre for hundreds of years. When these rocks are weathered and the debris is gathered by erosion and transported into the meadows and valleys of the northern portion of the state, a soil of great richness is produced; grasses, sedges, shrubs and forest trees grow vigorously.

In area these eruptive rocks underlie about one-fourth of Minnesota to the north and west of the line just drawn from Taylor's Falls through Anoka, New Ulm and Tracy to South Dakota. The great field of volcanic activity was almost the entire tract north of Lake Superior in Minnesota. Thousands of square miles were overflowed by lava beds and the exudations of hundreds of dikes which welled up from the deep-seated plastic rocks. Cracks in the old rocks some of them of huge extent were made across the state to the south and southwest and filled with this plutonic matter. They can be seen today in almost every county where the granitic and gneissic rocks appear. The chemical composition of the basic eruptive rocks will appear from the following selected analyses, also made in the laboratories of the State University:

VII. Medium grained diabase, north shore Lake Superior; mean of five analyses; analysis by H. B. Greeley.

VIII. Thomsonite-bearing diabase, north shore Lake Superior; analysis by Prof. C. F. Sidener.

IX. Columnar diabase, Grand Marais, north shore Lake Superior; analysis by Professor C. F. Sidener.

X. Porphyritic quartz diabase, Saint Augusta, Stearns county; analysis by A. A. Finch.

XI. Peridotite, Minnesota river bottoms below Motley; analysis by A. D. Meeds. Bull. 157, U. S. Geol. Survey, Granites, granite gneisses, etc., of the Minnesota river valley, p. 113.

XII. Porphyritic gabbro schist, Granite Falls; analysis by E. J. Babcock. Bull. 157, U. S. Geol. Survey, p. 89.

XIII. Porphyritic diabase near the base of Caribou Peak, north shore Lake Superior; Professor C. F. Sidener.

XIV. Olivine gabbro, Sec. 19, T. 65, R. 9 W.; Dr. H. W. Stokes. Journal of Geology I, p. 712.*

XV. Normal gabbro, Sec. 35, T. 61, R. 12 W.; Dr. H. W. Stokes. Journal of Geology I, p. 712.*

	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	Average
Silica, SiO_2	48.86	46.80	52.62	58.72	43.65	47.43	47.05	45.66	46.45	48.58
Alumina, Al_2O_3	12.99	15.21	15.75	16.53	6.81	23.66	32.03	16.44	21.30	17.84
Ferric Oxide, Fe_2O_3	20.42	13.13	15 83	9.56	21.10	13.06	2.01	0.68	0.81	13.33
Ferrous Oxide, FeO	....	....	....	....	....	....	....	13.80	9.57	
Lime, CaO	11.99	11.11	8.90	6.37	4.86	11.21	15.85	7.23	9.83	9.71
Magnesia, MgO	....	8.13	3.71	1.36	12.91	3.15	.15	11.57	7.90	5.43
Potash, K_2O	2.14	0.01	0.19	4.41	0.52	0.42	0.05	0.41	0.34	0.94
Soda, Na_2O	3.66	1.95	2.07	2.13	0.43	0.41	1.00	2.13	2.14	1.77
Titanic dioxide, TiO_2	....	....	....	....	....	....	....	0.92	1.19	....
Water, H_2O	1.46	2.79	1.81	0.81	*7.46	0.90	1.36	0.90	1.16	2.07
Total	101.52	99.13	100.88	99.71	98.86	100.24	99.50	†100.03	‡100.75	99.57

*CO_2 = 1.12 %. †Incl. NiO 0.16 and P_2O_5 0.05. ‡Incl. NiO 0.04 and P_2O_5 0.02.

Sandstones and quartzites.—The third group embraces typical sandstones and quartzites. These rocks do not lie in distinct and broad areas; they are rather in the form of narrow belts sandwiched in between the dolomitic rocks in the southeastern counties and the eruptive flows of northeastern Minnesota, save in the one expanse of quartzite which appears around New Ulm, thence southwest and across Cottonwood, Rock and Pipestone counties into South Dakota and Iowa. Attention is called to the high percentage of silica in these rocks.

XVI. Red quartzite, Pipestone; analysis by Professor J. A. Dodge.

XVII. Pink sandstone, Hinckley; analysis by Professor J. A. Dodge.

XVIII. White Saint Peter sandstone, Fort Snelling; analysis by Professor J. A. Dodge.

* Nos. XIV and XV were inserted in the reprinting of the Bulletin because of their typical character.

XIX. Light gray sandstone, Dresbach; analysis by Professor J. A. Dodge.

XX. Red sandstone, Fond du Lac, analysis by Professor J. A. Dodge.

XXI. White, friable sandstone, Jordan; analysis by Professor J. A. Dodge.

XXII. Gray slaty quartzite, Wauswaugoning bay, Lake Superior; Professor C. F. Sidener. Geol. & Nat. Hist. Survey Minnesota 13th an. rep. 1885, p. 100.

	XVI	XVII	XVIII	XIX	XX	XXI	XXII	Aver'ge
Silica Si_2	84.52	98.69	97.67	81.47	78.24	81.19	81.86	86.23
Alumina Al_2O_3	12.33	1.06	1.31	8.90	10.88	10.44	9.87	7.83
Ferric oxide Fe_2O_3.	2.12	......	0.55	.....	3.83	.....	1.44	1.13
*Ca Carb. $CaCO_3$. ..	0.55	0.75	0.74	3.38	1.69	1.00	0.82	1.28
†Mg Carb. $MgCO_3$. .	......	0.22	0.44	1.02	3.30	0.84	1.70	1.05
Potash K_2O	0.11	......	0.02	4.20	1.67	3.60	.45	1.43
Soda Na_2O	0.34	0.17	0.15	0.39	0.06	0.66	1.61	.48
Water H_2O	......	......	......	.....	.....	.....	1.43	.....
Total	99.97	100.69	100.88	97.37	99.67	97.73	101.54	99.43

*Recalculated from calcium oxide.
†Recalculated from magnesium oxide.

The soil qualities of sandstones and quartzites.—The sandstones and quartzites alone make a most barren soil; they are almost entirely destitute of the essentials of plant food. Almost entirely silica in their chemical composition, very nearly insoluble in water, hard and extremely obstinate in their physical character, they are most forbidding to all forms of vegetable life. Yet, in soils the contents of these rocks have their uses. Their *debris* does not pack into such an impervious mass as does clay, nor become crystalline and compact like the carbonates, but the grains lie loosely upon each other permitting free circulation of water, and in this way serving the double purpose of draining away the superfluous waters of level tracts,—preventing stagnation on the one hand, and on the other aiding in securing a supply of water from great depths through capillary action in time of drought. In the Gulf States there are large tracts of sandy soil. With the abundance of rain which annually falls in that section large crops are produced on land which in the upper Mississippi valley would be almost barren. In this state a sandy soil is not desirable for farming purposes. The sandy plains existing are due to the distribution of the disrupted sandstone and quartzite formations through the agency of the glaciers of the successive stages of the glacial invasion.

The calcareous and siliceous shales.—The fourth group is that of the calcareous and siliceous shales, partly Cambrian, partly Cretaceous and partly Glacial in age. While they are at the present time of no great extent, before the Glacial period they were probably spread over many square miles of Minnesota. They must have formed the underlying rocks over a considerable belt in southern Minnesota where the edges of the Cambrian rocks came to the surface, and to the west and northwest, where the Cretaceous—Fort Pierre shales of the Dakotas—extended into the state, a great extent of our territory must have been covered, possibly more than half the state. The soft and friable condition of these rocks caused them to be easily eroded by the ice which was pushed down from the north during the Glacial epoch.

The calcareous shales possess some peculiar, and for the agriculturist, valuable properties. Chemically, as will be seen, they contain in large measure some of the essential elements of plant food, and they are partially soluble; physically, they are not so heavy and compact as clays, they are easily broken up, allow roots to push into them, and they crumble and become finely pulverized under the action of sun and rain. The soil produced by them is not a heavy clay, but rather a mingled clay and sand,—and they will doubtless make, under some circumstances, an excellent loamy soil.

The siliceous shales contain a far less amount of soluble material than do the calcareous shales. There are two types of these shales in the state: those that stand intermediate between the dolomites and sandstones of the southeastern Minnesota succession and those which are directly or indirectly due to the ice of the Glacial period. The first type represents a rock originally very different from the existing one, the change being effected by combined solution, erosion and transportation. The existing condition may be regarded as a transition from a rock of quite diverse character towards a very clean bed of sandstone.

In the following table of analyses are included the decomposed granitic rocks which occur in several portions of the state. Along Birch Cooley, in the Minnesota river bottoms below Redwood Falls, at Granite Falls, and elsewhere, these rocks are an important soil constituent.

XXIII. Decomposed gneiss, Birch Cooley; analysis by A. D. Meeds.

XXIV. Siliceous clay, thought to be Cretaceous Mankato; Prof. S. R. Peckham. Geol. & Nat. Hist. Survey Minn., Am. Rep., 1880, p. 153.

XXV. Dark shaly bands Minneapolis building stone, Trenton limestone; Prof. W. A. Noyes.

XXVI. Contact clay between Shakopee limestone and Jordan sandstone, mouth of Blue Earth river; Professor C. F. Sidener. Geol. & Nat. Hist. Survey Minnesota, 11th An. Rep. 1884, p. 181.

XXVII. Stratum of easily crumbling calcareous rock above the building stone, Minneapolis, Minn., by H. V. Winchell.

	XXIII	XXIV	XXV	XXVI	XXVII	Average
Silica SiO_2	41.71	70.10	15.84	68.70	20.38	43.35
Alumina Al_2O_3	34.61	16.99	4.93	18.04	26.77	20.27
Ferric oxide Fe_2O_3	4.58	......	4.00	1.53	1.57	2.34
Ferrous oxide FeO	6.88	......	......	......	13.74	......
Lime CaO	1.16	......	......	1.24	0.70	......
Magnesia MgO	0.22	......	......	0.56	......	......
Soda Na_2O	0.11	......	......	0.24	......	......
Potash K_2O	Trace	10.69	......	5.28	......	......
Water H_2O	12.69	1.98	......	1.40	......	4.02
Sulphuric acid SO_3	......	0.23	......	......	......	......
Calcium carbonate $CaCO_3$	......	......	36.47	......	28.16	......
Magnesium carbonate $MgCO_3$	......	......	14.21	......	11.18	......
Organic matter	......	......	1.26	......	......	......
MgO with SiO_2	......	......	0.14	0.09	......	......
Total	101.96	99.99	96.86	97.08	102.50	......

The Carbonates.—The last group, or the carbonates, occupy a large area in southeastern Minnesota, and they probably underlie a considerable area of the Red river valley. At one time, I have no doubt, they covered the entire state as well as Wisconsin and the Dakotas to the right and left, and even Manitoba and Ontario on the north. They are crystalline and firm of texture, and they form an excellent building stone. In composition they contain carbonic acid, lime and magnesia, with small quantities of other plant foods. In the southeastern portion of the state, over some hundreds of square miles, these rocks are not covered by Glacial *debris;* for there we see a portion of the old Glacial island which lies largely in Wisconsin and Illinois—a tract of land over which the ice did not spread during the period when all the rest of the northwest was buried deep beneath the glacier. In this corner of the state, then, these carbonates by their decay have produced the surface soil; while by the breaking up of boulders in every other portion of the state they have done their work in soil building. But in the breaking up of these rocks into farming soils so much is soluble that only a small part remains behind for soil building, and this is largely the impurities of the rock, such as silica and alumina; while the other constituents, lime, magnesia, soda, sulphur and phosphorus remain behind in small quantities.

XXVIII. Compact dolomite, Dresbach; analysis by C. S. Chappel.

XXIX. Compact dolomite, Nininger; analysis by Mary E. Bassett.

XXX. Dolomite, bottom layer quarried at Mankato; analysis by C. L. Herron.

XXXI. Dolomite, buff-colored Kasota stone, Kasota; analysis by H. C. Carel.

XXXII. Dolomite, porous, Frontenac quarries; analysis by J. G. Cross and E. P. Sheldon.

XXXIII. The buff limestone, Minneapolis, analyzed as a whole; analysis by Professor J. A. Dodge.

XXXIV. The buff limestone, Minneapolis; analysis by W. A. Beach.

XXXV. "Galena limestone", Section 9, Spring Valley. Chemist unknown.

XXXVI. Mankato cement rock, Mankato, Minn.; analysis by W. C. Smith.

XXXVII. Frontenac dolomite, quarried extensively as a building stone, Frontenac, Minn.; analysis by E. P. Sheldon.

XXXVIII. Siliceous dolomite, Goodhue co.; analysis by G. A. N. King. Results as reported have been recalculated.

	XXVIII	XXIX	XXX	XXXI	XXXII	XXXIII	XXXIV	XXXV	XXXVI	XXXVII	XXXVIII	Average
Ca. carbonate, $CaCO_3$	47.96	46.46	47.22	44.78	54.34	79.18	77.21	70.53	48.74	54.40	49.95	56.43
Mg. carbonate, $MgCO_3$	44.45	48.92	37.50	34.26	41.00	6.38	3.91	23.49	29.27	41.63	40.41	31.94
Iron carbonate, $FeCO_3$	1.41	....	0.73	0.59	0.79	....	....	....	....	0.90	....	4.11
Silica, SiO_2	5.15	1.75	13.01	18.96	1.84	8.16	9.99	4.57	13.39	3.36	8.01	6.49
Alumina, Al_2O_3	1.13	0.43	1.31	1.09	0.85	2.67	3.43	....	4.17	....	....	....
Ferric oxide, Fe_2O_3	....	....	....	....	....	2.43	2.69	0.73	1.52	1.11	0.31	1.60
Soda Na_2O	....	....	....	....	....	trace	....	....	0.25	....	1.26	....
Potash K_2O	....	....	....	....	....	trace	....	....	0.26	....	....	....
Water H_2O	....	....	0.21	0.37	0.03	....	....	....	....	....	....	....
Lime CaO	....	....	....	....	....	trace	....	....	....	0.12	0.13	....
Magnesia MgO	....	....	....	....	....	0.04	....	....	....	....	....	....
Carbondioxide CO_2	....	....	....	....	....	....	....	....	....	....	....	....
Organic matter	....	....	....	....	....	0.80	....	....	0.14*	....	....	....
Totals	99.30	97.56	99.98	100.05	98.94	99.66	99.14	99.32	97.74	101.61	100.07	....

* Phosphoric acid, P_2O_5.

Application and Summary. The foregoing analyses disclose rocks of a varied composition within the borders of the state. Were they the rock-floor which, directly beneath the workable soils were affording replenishment of the mineral substances of these soils, it would not be difficult to read the characters of the best crops in the tables of chemical constituents. But the work of the glacial period of geologic history must be given recognition. It is not alone that all the foregoing rocks have been covered by glacial drift in places to the depth of hundreds of feet by rock debris, but the very rocks themselves have been broken, torn up and scattered over wide areas.

What does occur, then, as soil-making material is the fragments of these rocks torn from the ledges and scattered broadcast over that glacial plain which the surface of the underlying rock-formations so plainly shows. True, much material derived from the underlying rocks within this state has been carried across the boundary to form the soil-material of neighboring states, while on the other hand no small amount brought from other regions has been deposited within the borders of this commonwealth. Its present occurrence is in the form of particles fine and coarse, which, by affording a large proportion of surface to bulk are rapidly disintegrating and yielding their chemical elements to be used as the food of growing plants.

If a further summary of this paper were written it would state: The term soil is defined. Soils are made by the mingling of rock-debris with the remains of organisms, chiefly plants, and its degree of fertility depends upon physical and chemical conditions combined. A soil fertile for one crop is not necessarily the best one for another type of plants. The chemical elements constituting the essential plant foods are few, yet these must be in such condition that the crops can readily secure them from the multitude of mixtures in which they occur. The rocks of Minnesota are classified under five groups; 1, acid crystallines; 2, basic crystallines; 3, sandstones and quartzites; 4, calcareous shales, and, 5, the carbonates. Among these, granitic rocks and basic eruptive, which occupy large areas beneath the drift in the northern and western portions of the state, furnish many important food elements, particularly alkalies and alkaline earths.

The sandstones and quartzites among the most barren soil producers have mingled with other substances their beneficent uses. The calcareous and siliceous shales spring from widely divergent geologic periods and bring to the making of soils somewhat different physical and chemical factors. Their influence is wholesome and strengthening. Finally the carbonates come before the eye in this chemical review. They yield, for soil making, carbonic acid, lime, magnesia and small quantities of other compounds. When the condition of a soil is reached, but a small percentage of these rocks is left, but this is a substantial part and enters into the constitution of the best soils of the state They appear in full force in the southeastern corner of the state where stands a portion of that old glacial island, a tract over which the ice did not flow during the period when all the rest of the state was buried deep beneath the glacier.

December 8, 1891.